Long Term Water Augmentation Committee
Webinar Instructions

* If you have video capabilities, we would love to see your face.

* If you have joined via your computer and had the computer call your phone for the audio connection, you must click on your computer speaker icon to mute your computer speakers. Otherwise it will create a horrific feedback noise.

* The meeting and the chat will be recorded and saved.

* Please mute yourself when you're not speaking.

* If you would like to speak please type your name in the chat. Throughout the meeting we will unmute and call on people to speak.

* You can also type your questions/comments in the chat if you prefer and we will read and respond to those through the meeting.

* If you have technical difficulties, contact Theresa Johnson by sending her a private message in the chat box.

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Governor

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Governor's Water Augmentation, Innovation and Conservation Council

Long Term Water Augmentation Committee

Meeting Agenda

May 22, 2020, 10:00 a.m.-12:00 p.m. | **Webinar only**

I. Welcome and Opening Remarks

II. Potential Water Augmentation Options for Committee Consideration
   a. Weather Modification: Chuck Cullom, CAP
   b. Forest/Grassland Management: Marcos Robles, TNC and Bruce Hallin, SRP
   c. Phreatophyte Management: Sarah Porter, Kyl Center

III. Wrap Up, Closing Remarks and Adjournment

This is a webinar meeting and is open to the general public. A copy of this meeting notice is posted at the Arizona Department of Water Resources, First Floor Public Notices Bulletin Board, 1110 West Washington Street, Phoenix, Arizona 85007. If you have any questions, please contact Cyndi Ruehl at cruehl@azwater.gov 602-771-8538.

DISCUSSION

- Should this potential augmentation strategy be added to the Arizona toolbox as a viable consideration for communities?
- Does this potential strategy need more research to answer that question and if so what do we need yet to know, or is it just not a feasible tool to add to the toolbox?
- Do the benefits now, or potentially in the future, of the additional water it provides outweigh the costs?

Brief History of Snowpack Augmentation in the Colorado River Basin

1. Identified as augmentation opportunity in Reclamation's 1974 Westwide Study (response to augmentation study requirements of CBRPA)

2. Reclamation followed up with CREST Program 1982

3. Colorado (1959 – P), Wyoming (2005 – P), Utah (1952 – P) operate and regulate snowpack augmentation programs

4. 1992 Arizona Snowpack Augmentation Study

5. Recognized as low-cost augmentation strategy across the west (California, Idaho, Colorado, Wyoming, Utah, operate long-term programs)

6. Wyoming study (2005 – 2014)

North American Weather Modification Council www.nawmc.org

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Update on Snowpack Augmentation Research and Verification

1. Science and application of winter cloud seeding (snow augmentation)

2. Efficacy of snowpack augmentation programs

3. Potential of extra-area effects

4. Environmental impacts from seeding materials (Silver Iodide)

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Conditions Necessary for Winter Cloud Seeding

Meteorological conditions are observed to track the following:

Coverage:

- Targeted clouds must persist long enough for adequate seeding to take place

Winds:

- Forecasted trajectory of orographic (mountain) storm clouds must pass over ground-based generator locations and the target seeding area

Temperature:

- Cloud temperature of less than -8 degrees Celsius (if using Silver Iodide as seeding agent)

Moisture:

- Presence of enough super cooled liquid water

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Snow Augmentation Process

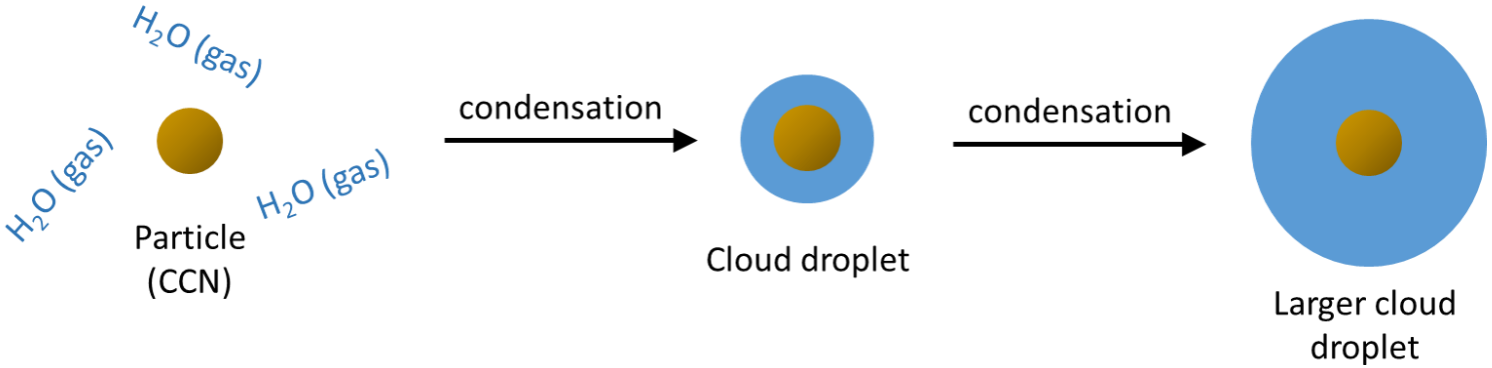
Snowpack/Water Enhancement

1. Moist air rises as it flows over the mountains, cooling and creating clouds composed of super-cooled water droplets.
2. Minute amounts of silver iodide in solution are sprayed across a propane flame or released from an aircraft-mounted flare. The air flow up the mountain barrier carries the particles into the clouds.
3. The silver-iodide crystals provide nuclei for the formation of ice crystals.
4. By freezing of droplets and deposition of vapor, ice crystals form and grow progressively larger, forming snowflakes large enough to precipitate to the ground.

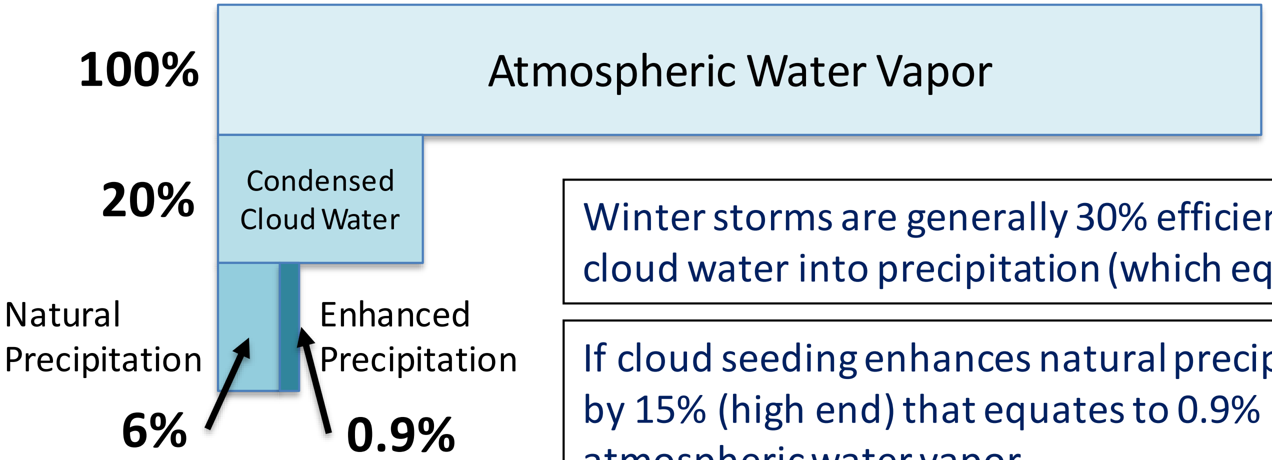
To find out more about weather modification and participating agencies, visit the North American Weather Modification Council online at www.nawmc.org

Ice Nucleation and Atmospheric Moisture

Cloud Condensation Nuclei (CCN): small particles upon which water vapor condenses



General thermodynamics of orographic cloud systems:



Only 20% of moist air (water vapor) condenses as it cools from being forced upward over mountain ranges

Winter storms are generally 30% efficient in converting condensed cloud water into precipitation (which equates to 6% of water vapor)

If cloud seeding enhances natural precipitation by 15% (high end) that equates to 0.9% of atmospheric water vapor

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Dispersion of Seeding Material

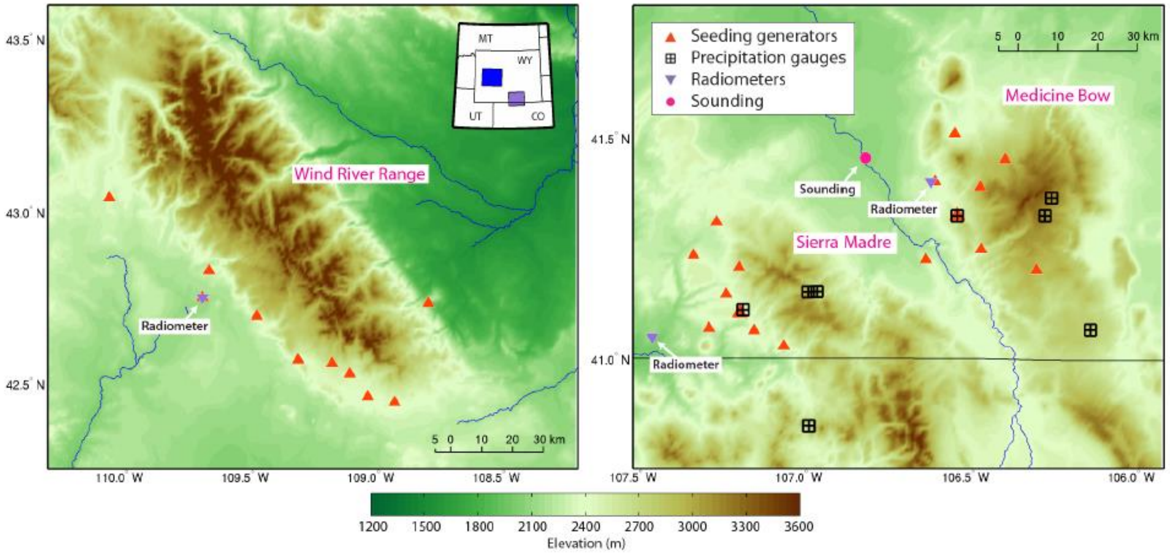
- High elevation ground-based generators or aircrafts
- Preferred seeding agent: silver iodide (most effective for winter seeding @ temperatures < -8 ^{O}C)
- Release of silver iodide by burning flares (acts as CCN)
- Approx. 2-3 kg of silver iodide can be released per generator in a season

Wyoming Weather Modification Pilot Program (2005-2014)

Randomized Seeding Experiment (RSE):

- To evaluate the efficacy of cloud seeding in enhancing winter precipitation
- One of two mountain ranges was randomly selected to be seeded when both have achieved the conditions of a seeding criteria:
  - Mountain top temperature colder than -8 degrees Celsius
  - Wind direction that will transport the Silver Iodide into the target clouds
  - Presence of super-cooled liquid water (for droplet formation)

Wind River Range



Sierra Madre

Medicine Bow

Figure 1. Map of WWMPP facilities (see legend) in the Wind River (left, blue shaded box on inset map) and the Medicine Bow and Sierra Madre Ranges (right; purple shaded box on inset map).

Wyoming Pilot Program: Results

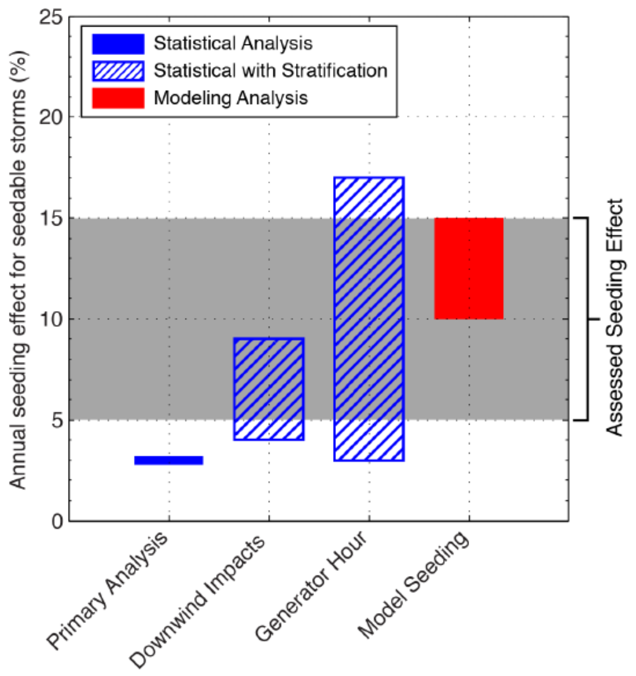


Figure 3. Estimation of seeding impacts on precipitation as determined by various analysis methods. Blue indicates results from the RSE. The solid blue is the primary statistical result, while the hatched blue represent the range achieved through stratification of the statistical data. The red bar represents the range of model seeding results. The accumulation of evidence leads to the assessed seeding effect as indicated by the gray shading.

Initial statistical analysis without data correction:

3% increase in precipitation

Data corrections:

- Occurrence of unintended downwind effects on the Medicine Bow by seeding over the Sierra Madre
- Insufficient amounts of silver iodide reaching the intended target (low generator hours threshold)

Assessed seeding effect: 5-15%

Extra-area Effects

What is the impact of seeding beyond the target area?

- Hunter 2009: Comprehensive Literature Survey on the Potential Extra-Area Precipitation Effects of Winter Cloud Seeding
- Paper assessed multiple cloud seeding studies (> 28) and the extent of seeding effects beyond a target area (up to 250 miles away)
- Evidence of positive seeding effects beyond target area (no decrease in precipitation)
- Extra area impacts affected by local climatology, uncertainty of natural precipitation distribution, level of seeding operations, etc.

Suspension Criteria

- Many snow augmentation programs have suspension criteria conditioned to SWE accumulation in the area (snowpack volume threshold)

Environmental Concerns: Silver Iodide

Background levels of silver from naturally occurring sources in parts per billion (ppb)

- Surface waters: 0.2 – 2.0 ppb

  (ATSDR, 1990. Agency for Toxic Substances and Disease Registry. Toxological Profile for Silver)
- EPA drinking water standard for silver: 100 ppb

Silver levels in precipitation/snow post-cloud seeding

- Studies indicate silver concentrations well below the EPA standard:
  - Sierra Nevada Mountains (2 sites): 0.02-0.4 ppb (post seeding) vs. 0.02 ppb (background)

    (Warburton et al., 1995. How the transport and dispersion of AgI aerosols may affect the detectability and seeding effects by statistical methods)
  - Silver in snow: 0.01-4.5 ppb (cloud seeding) vs. 0-0.02 ppb (unseeded storm)

    (Cooper and Jolly, 1970. Ecological effects of silver iodide and other weather modification agents)
  - San Juan Mountains (3-year study): no significant increase in silver levels

    (Teller et al., 1976. Disposition of silver iodide used as a seeding agent in ecological impacts of snowpack augmentation in the San Juan Mountains of Colorado)
- EPA exposure and risk assessment for silver:
  - Determined that cloud seeding not expected to contribute significant amounts of silver to water from precipitation

    (EPA, 1981. U.S. Environmental Protection Agency. An exposure and risk assessment for silver)

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Additional Research

Precipitation formation from orographic cloud-seeding (2018)

- PNAS February 6, 2018 115 (6) 1168-1173; first published January 22, 2018 https://doi.org/10.1073/pnas.1716995115
- *"These comprehensive observations provide unambiguous evidence that glaciogenic seeding of a supercooled liquid cloud can enhance natural precipitation growth in a seeded cloud, leading to precipitation that would otherwise not fall within the targeted region."*

Quantifying snowfall from orographic cloud-seeding (2020)

- PNAS March 10, 2020 117 (10) 5190-5195; first published February 24, 2020 https://doi.org/10.1073/pnas.1917204117
- *"Here, an approach employing radar and gauges is used to quantify snowfall by first isolating radar returns that are unambiguously the result of cloud seeding in regions with light or no natural precipitation and then quantifying the seeding-induced precipitation at the ground. The spatiotemporal evolution of snowfall from cloud seeding is quantified. Although this study focuses only on three cases, the results are a fundamental step toward understanding cloud seeding efficacy that, for over half a century, has been an unanswered question for water managers wishing to utilize the technology for water resource management."*

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Accelerated Forest Thinning to Increase Forest Resilience and Runoff

TNC
Marcos Robles
Rob Marshall
Jeanmarie Haney
Ed Smith
Dave Gori

NAU
Frances O'Donnell

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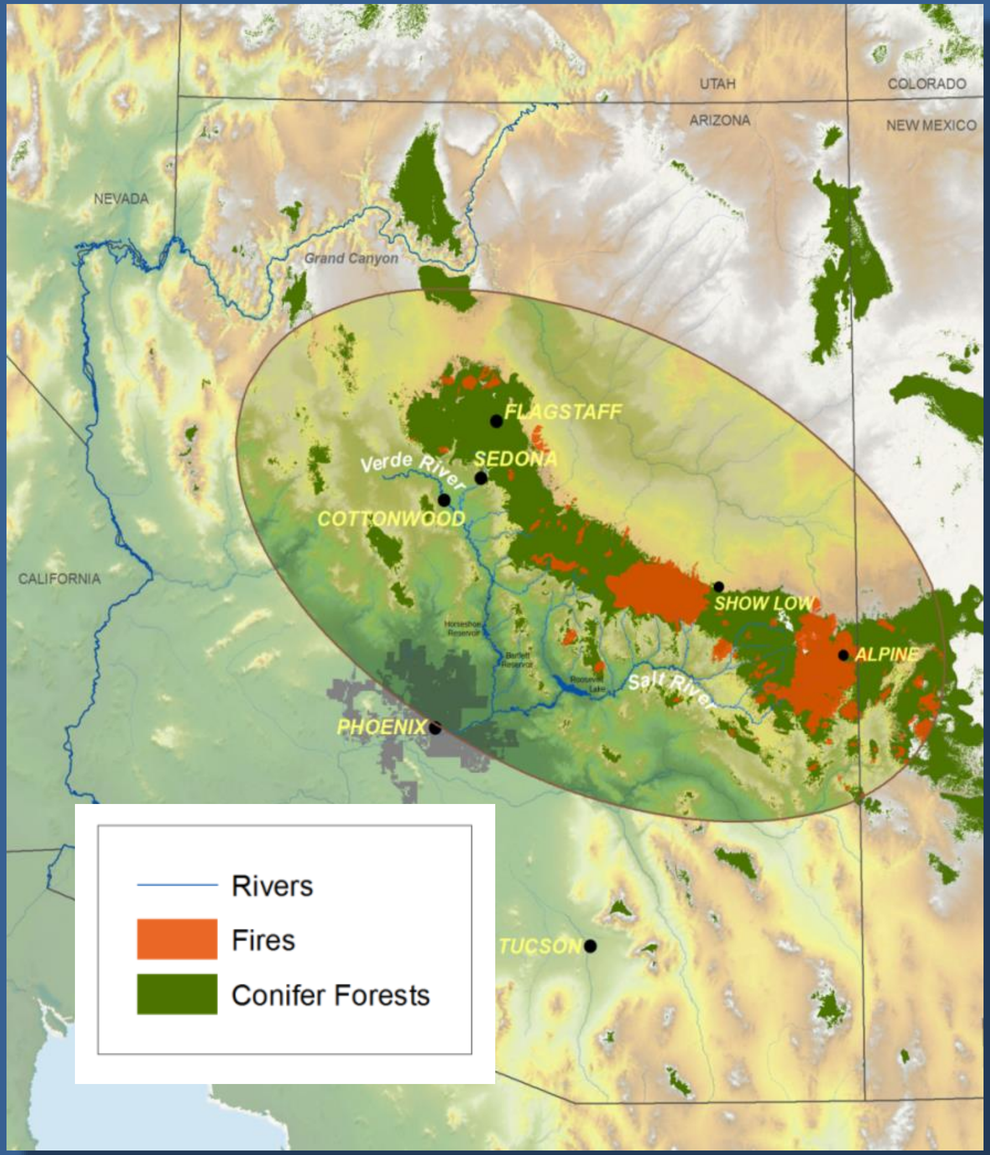
20% mortality of forests in headwaters that provide 40% Phoenix water supply

- Dense forests
- Drought
- Warmer Temps

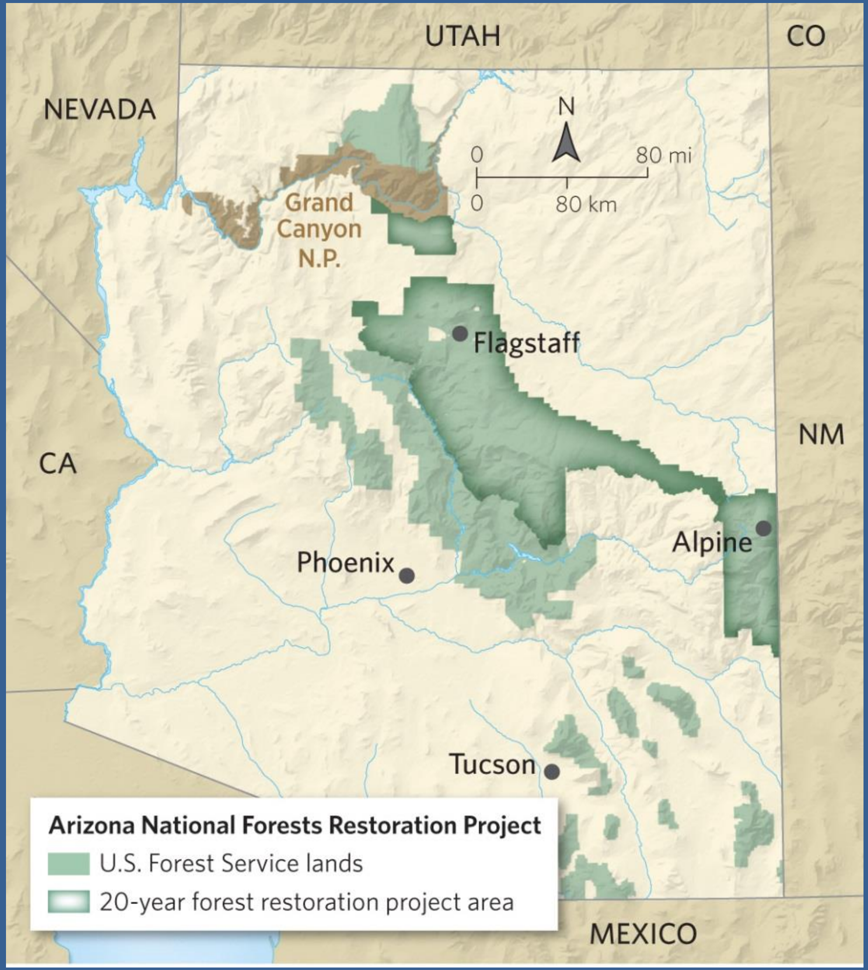


Sources: USFS 2013 & ADWR 2010 Arizona Water Atlas: Volume 8

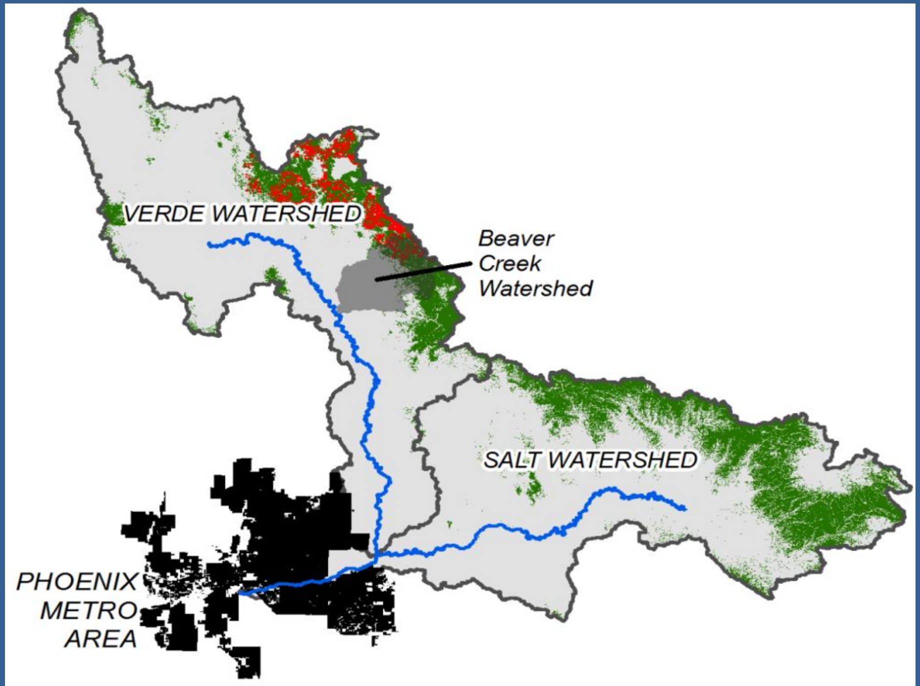
Can "big" efforts like Four Forest Restoration Initiative improve forest resilience and runoff?

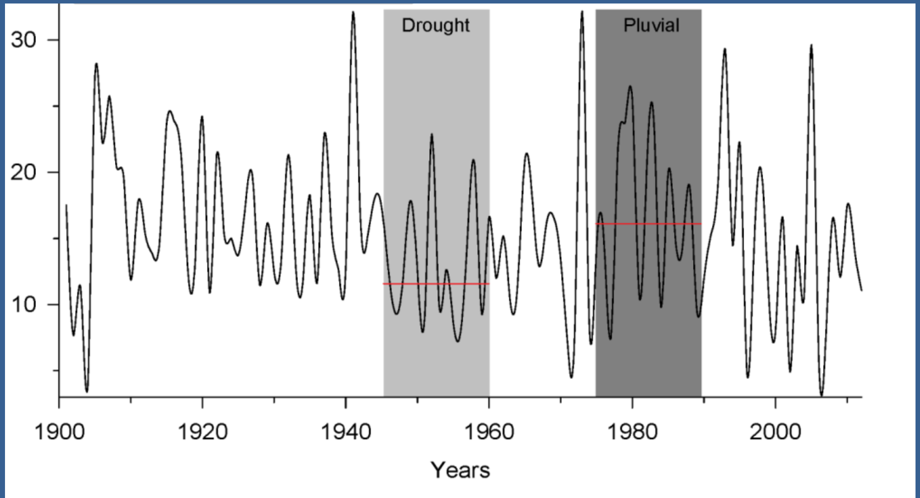
Photos: Arizona Daily Sun (Cyndy Cole), 4FRI USFS website

Phase 1: 588,000 acres in next 10 years



Estimate Runoff



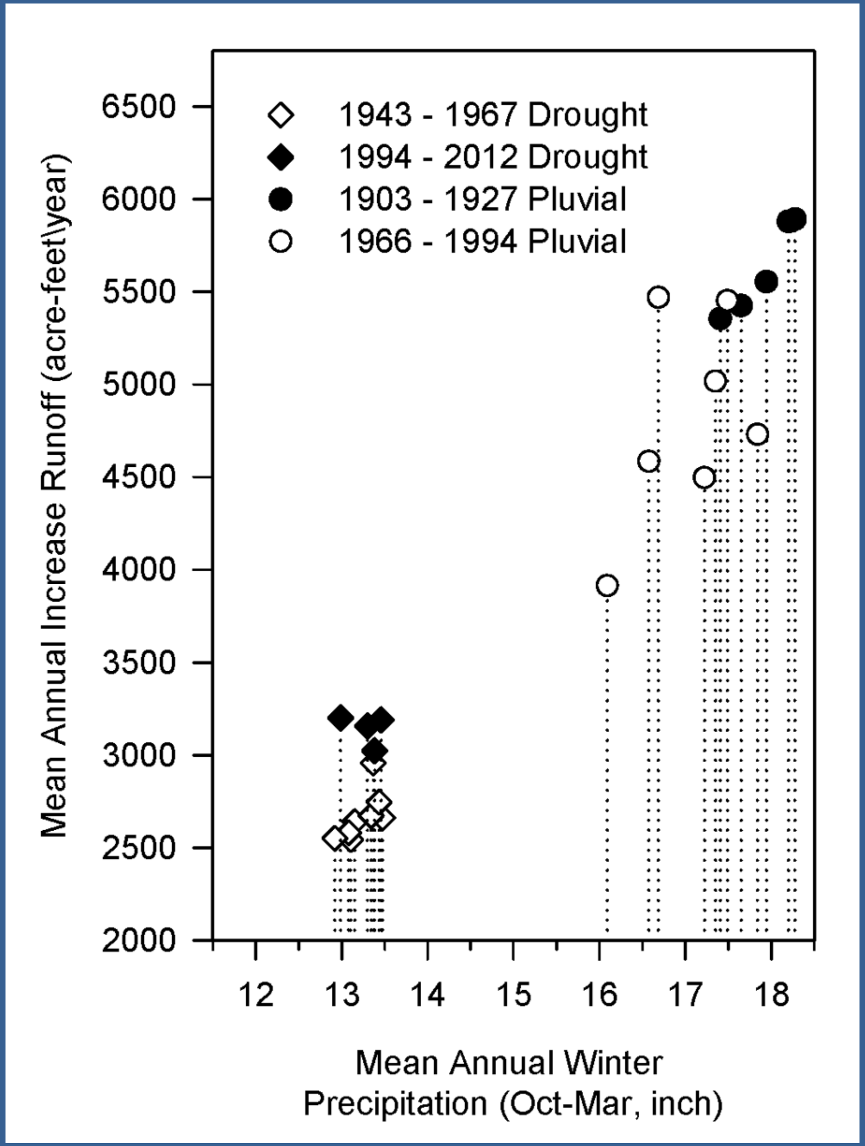


Geography:
Salt-Verde watersheds
Ponderosa Pine Forests
4FRI restoration project

Factors:
Drought + Wet Periods
Scale + Pace Restoration

Science:
Adapt empirically-derived model from historical experiments to modern day restoration project

20% increase in runoff



LTWA Question #1: Empirical Research

- ***20%*** increase (Headwaters); ***1-9%*** increase (municipal water supply); ***1-3%*** increase (Salt-Verde rivers)
- Empirical field-based, applicable to Northern Arizona ponderosa forest restoration

Other Studies

- Flow: 3 Simulation Model Studies (2 evaluating 4FRI)
- Fire: ***2-3x*** reduction in risk crown fires
- Drought Impacts: ***13%*** reduction ET losses

Sources: Robles et al. 2014, 2017, Fule et al 2012, Dore et al. 2010

LTWA Question #2/3: Implementation

2. Additional Research

- How durable, including maintenance burns?
- Effects of warmer temps on snowpack & streamflow.
- Measuring forest management effects on snowpack, soil moisture

3. Cost-Benefit Analyses

- Pre-emptive forest management costs vs. post fire recovery costs
- Wildfire Risk Assessments

Thank You

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PLOS | ONE

Effects of Climate Variability and Accelerated Forest Thinning on Watershed-Scale Runoff in Southwestern USA Ponderosa Pine Forests

Marcos D. Robles[1]*, Robert M. Marshall[1], Frances O'Donnell[2], Edward B. Smit
David F. Gori[4]

1 The Nature Conservancy Center for Science and Public Policy, Tucson, Arizona, United States of America, 2 Northern Arizona
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United States of America

PLOS | ONE

RESEARCH ARTICLE

A century of changing flows: Forest management changed flow magnitudes and warming advanced the timing of flow in a southwestern US river

Marcos D. Robles*, Dale S. Turner[©], Jeanmarie A. Haney[©]

The Nature Conservancy, Center for Science and Public Policy, Tucson, Arizona, United States of America

www.azconservation.org

Marcos Robles, mrobles@tnc.org

Forest Management and Watersheds

GWAICC Long Term Water Augmentation Committee
May 22, 2020

Bruce Hallin
Director Water Supply

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Watershed Conditions – Pre and Post Forest Restoration

Objective

Gain a better understanding of the impacts of forest restoration on the hydrology of the watershed.

- **Three Study Areas**
- **Type and Extent of Data Being Collected**
- **Research and Modeling Efforts**

Study Areas

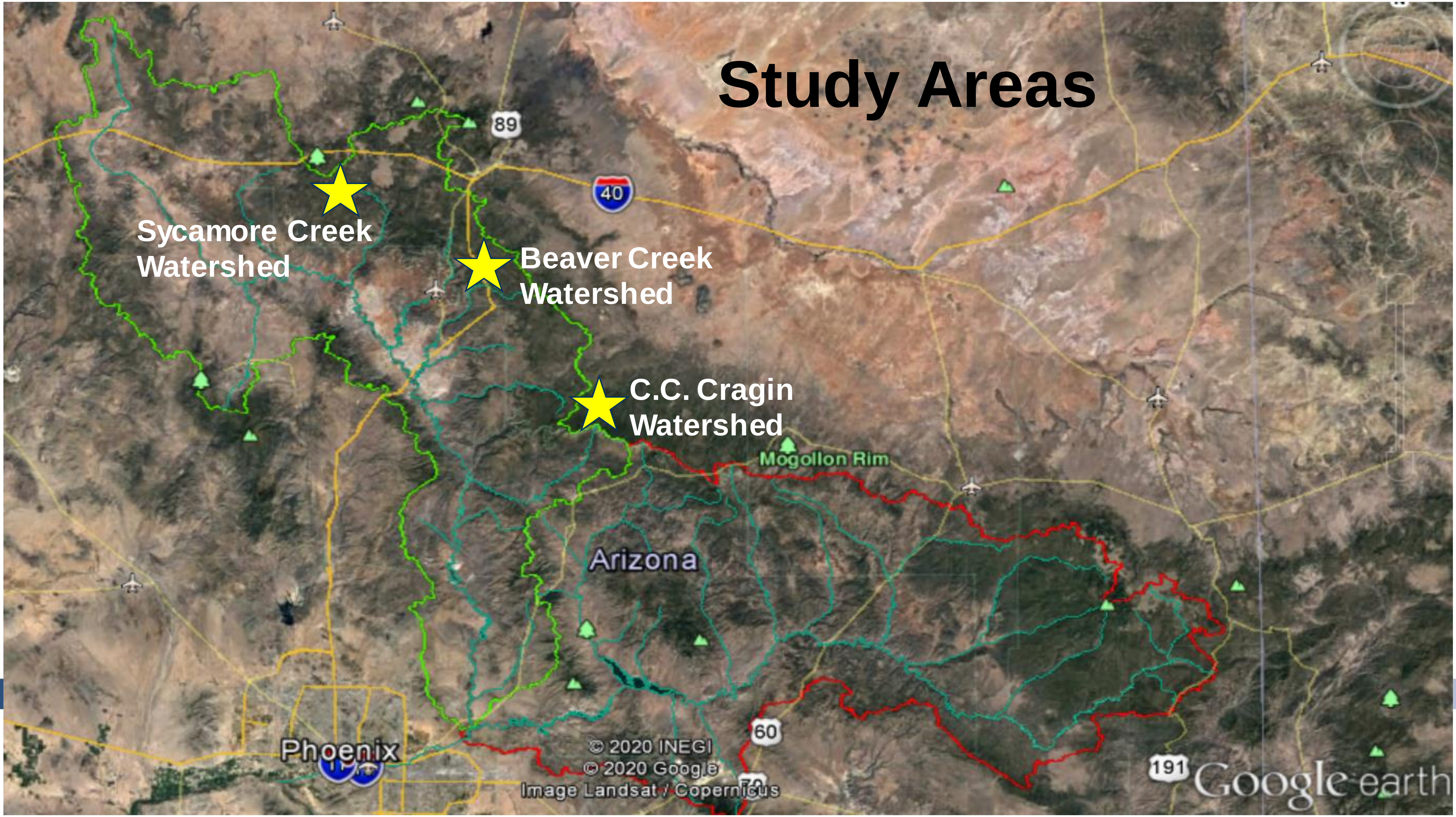
Sycamore Creek Watershed
Beaver Creek Watershed
C.C. Cragin Watershed
Mogollon Rim
Arizona
Phoenix
89
40
60
191
© 2020 INEGI
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Image Landsat / Copernicus
Google earth

Hydrologic Modeling

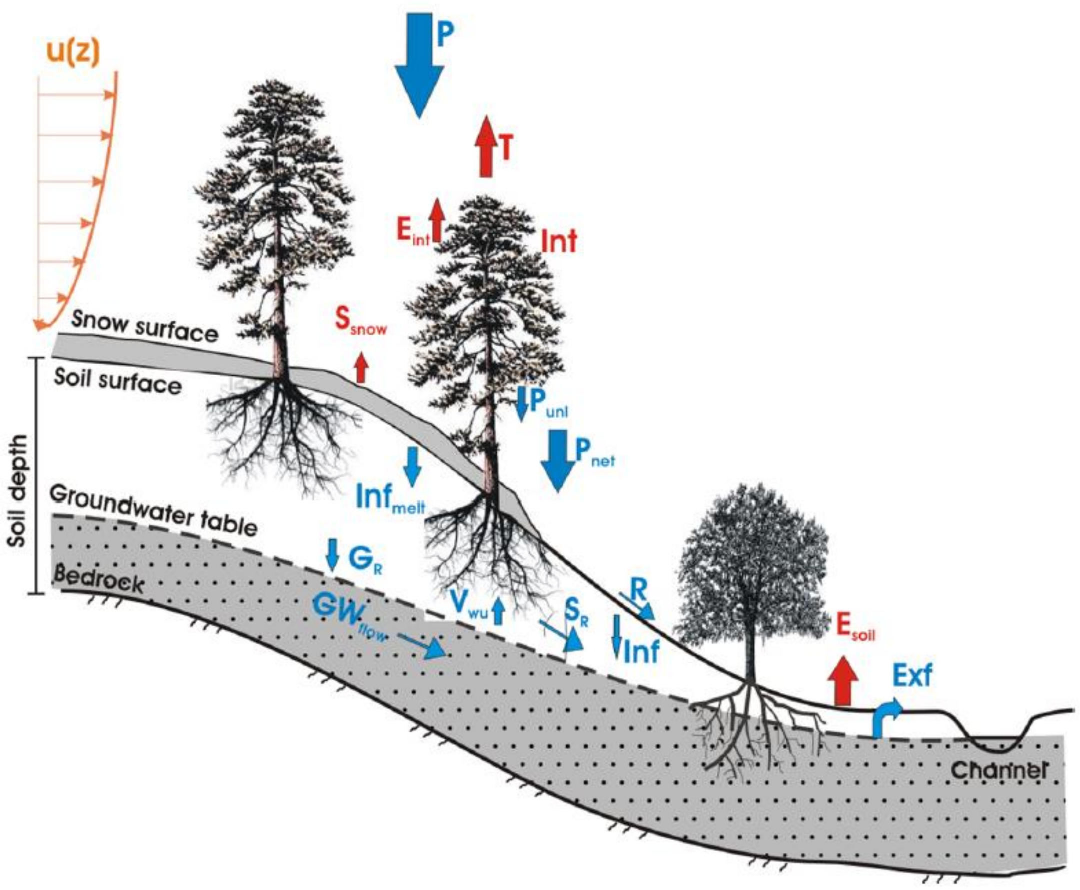
- **Research Questions**
  - How does thinning change the forest water budget?
  - How large are these changes relative to those due to climate change?

Forest Hydrology Model

Forest and terrain setup with LIDAR

Calibration/validation with SRP Flowtography and USGS gages

H. A. Moreno et al.: Hydrologic effects of forest thinning



Moreno HA, HV Gupta, DD White, and DA Sampson, 2016, Modeling the distributed effects of forest thinning on the long-term water balance and streamflow extremes for a semi-arid basin in the southwestern US. Hydrology and Earth System Sciences, 20, 1241-1267, doi:10.5194/hess-20-1241-2016

Forestry Modeling on the Sycamore Watershed

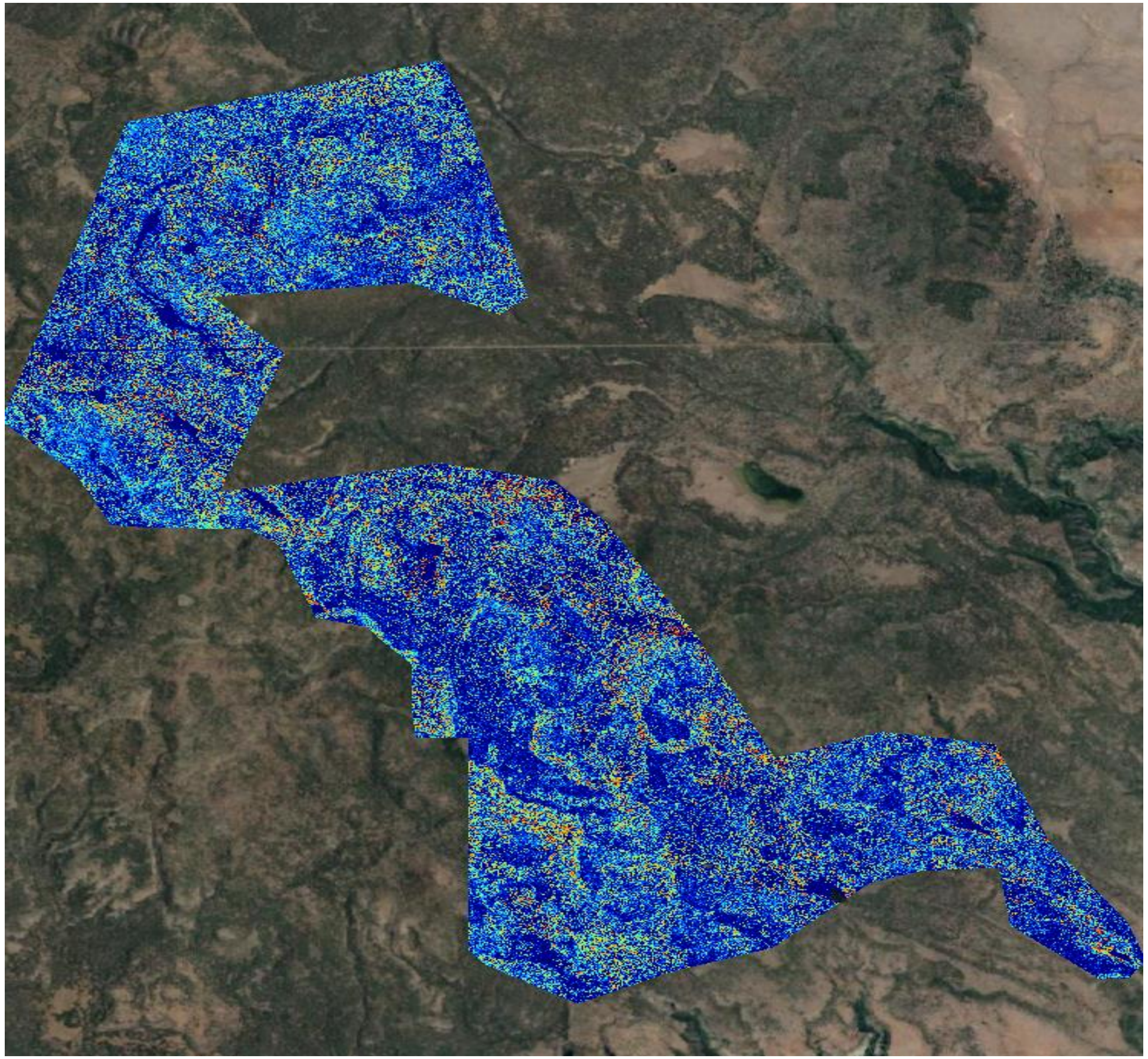
LiDAR Survey (November 2019)

Flowtography (Over 7 years of data collected)

- Middle Sycamore – 4 sites
- Lower Sycamore – 3 sites

10 Model Inputs

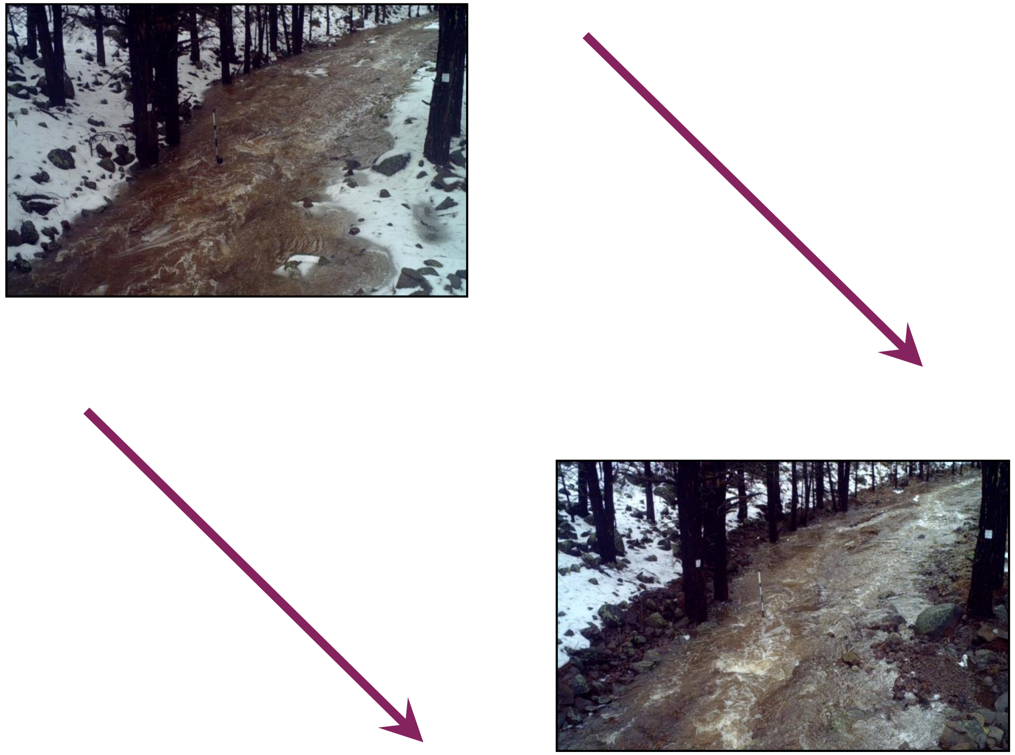
- *From Flowtography:* stage, calculated discharge, precipitation, soil moisture, images
- *From LiDAR Survey:* Leaf Area Index, Bare Earth Model, Tree Canopy Height, False Color Imagery, NDVI



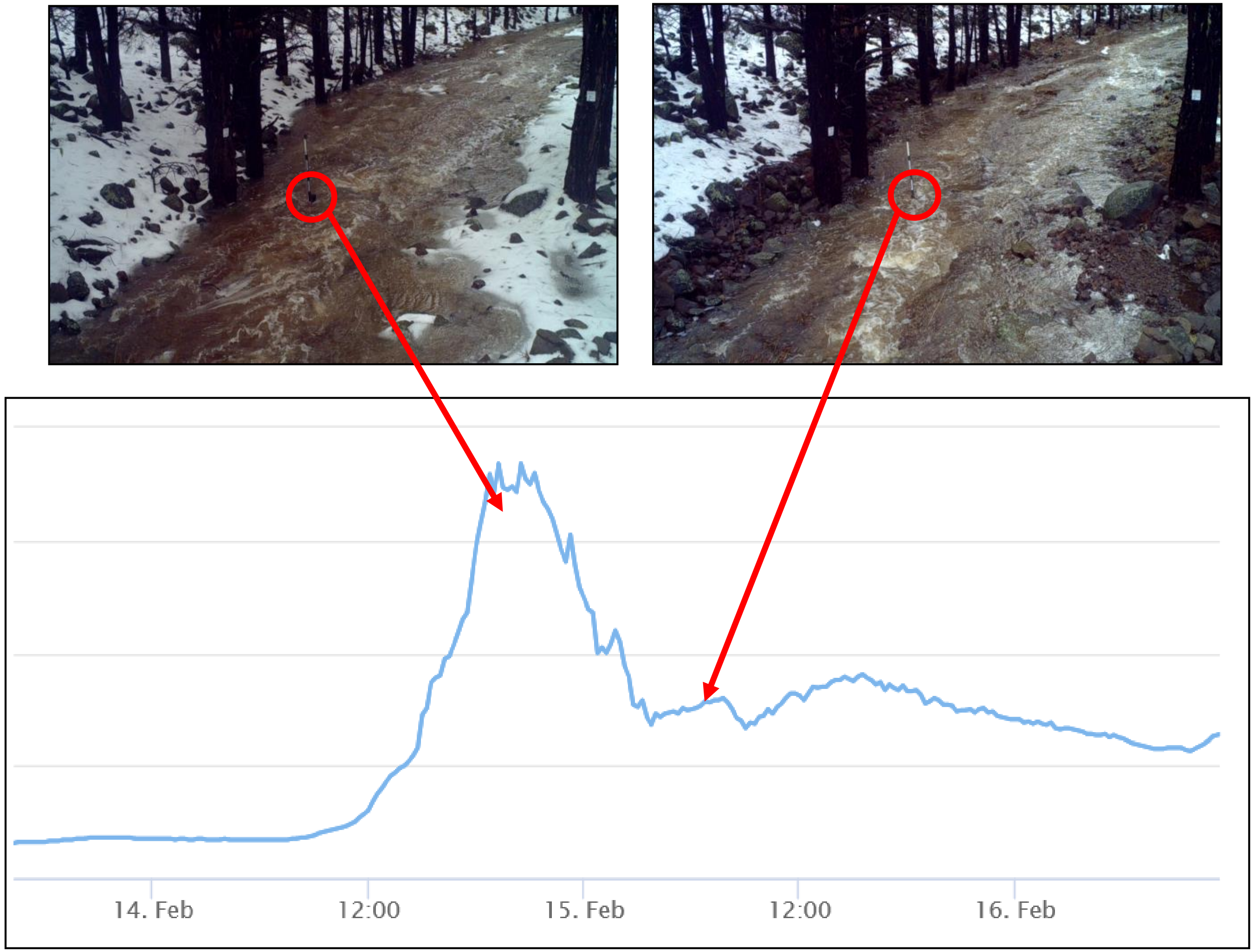
Canopy Height Model

SRP Flowtography: How It's Done

1. Collect time series event images



2. Use images to obtain stage data & calculate discharge

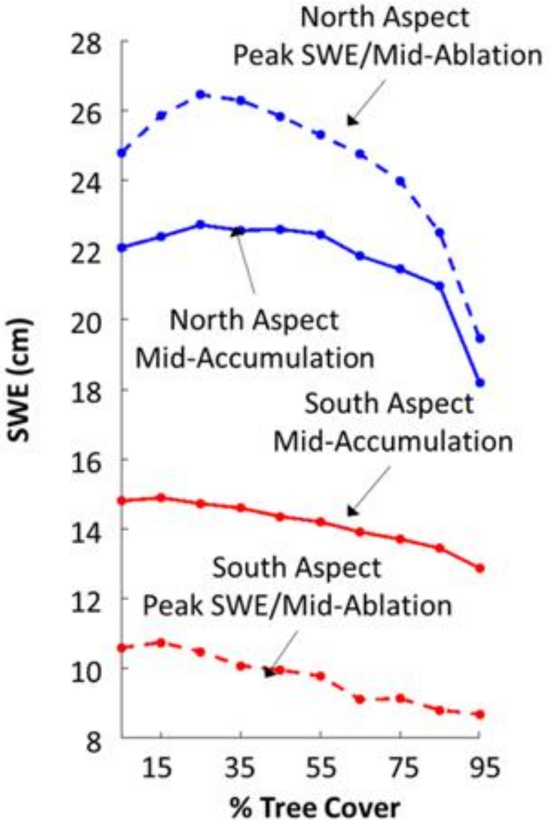


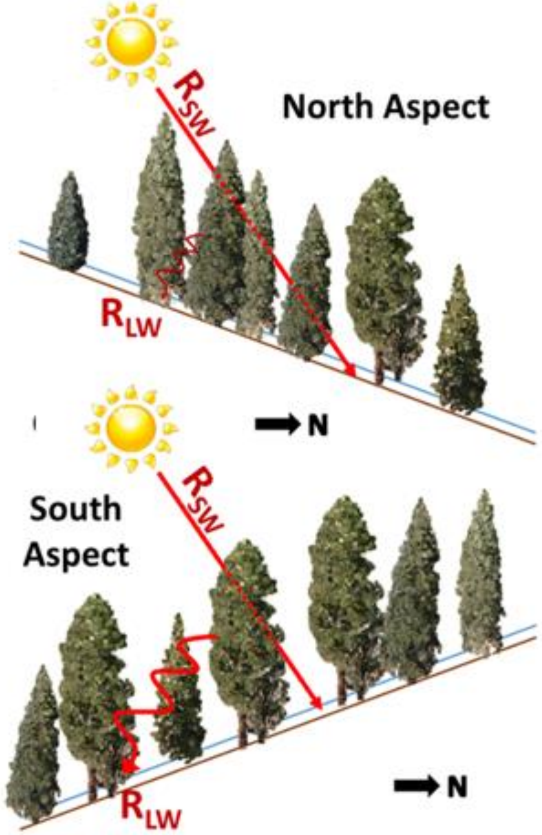
Beaver Creek Forest Thinning and Snowpack

Research Question

- How do different thinning strategies impact the snowpack?
  - e.g. Interception, Persistence, Sublimation, and Melt.

Not Thinned Thinned

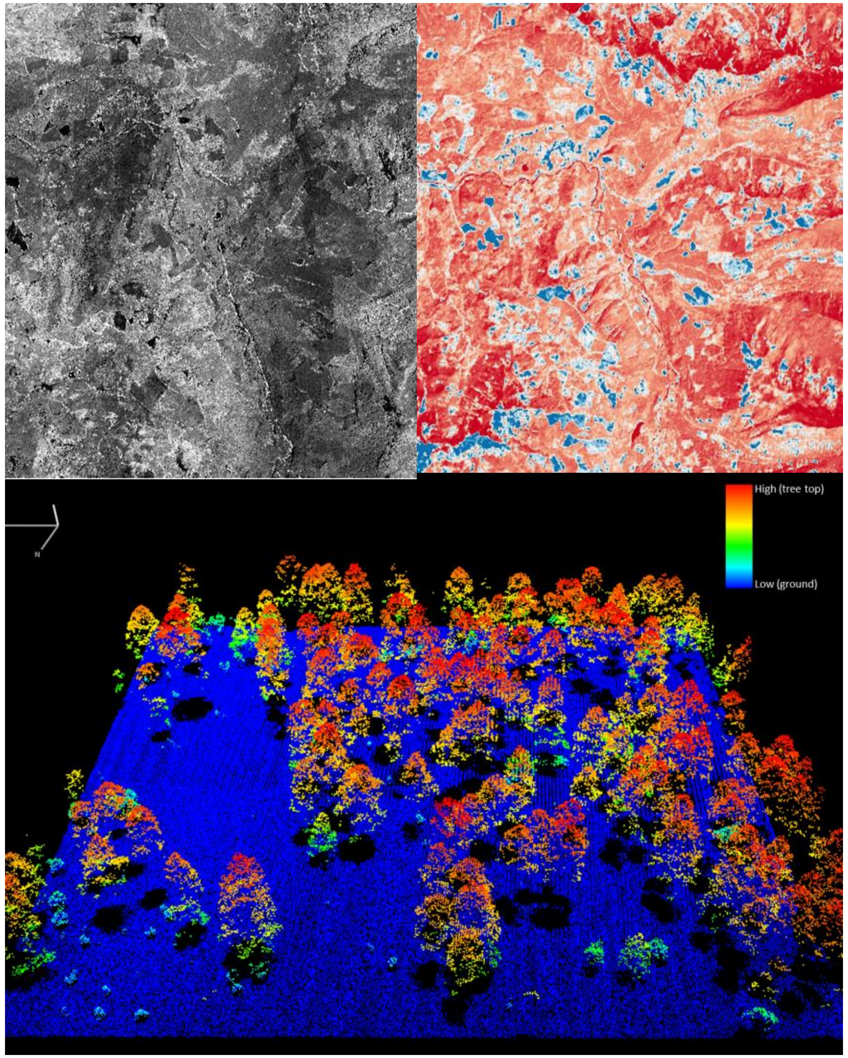




Cragin Forest Resource Characterization Research

Research Scope

- C.C. Cragin Watershed – 64,000 acres
- Use of multiple existing data sets
  - LiDAR, Forest Service Data, Multispectral Imagery
- Identify a preferred forest inventory method that can be scaled
- Create a forest inventory data set for Cragin Watershed



Research Benefits:

- Two different analysis methods to determine accuracy and costs
- Provides accurate data set for forest restoration projects, wildlife habit modeling, water and carbon benefit modeling

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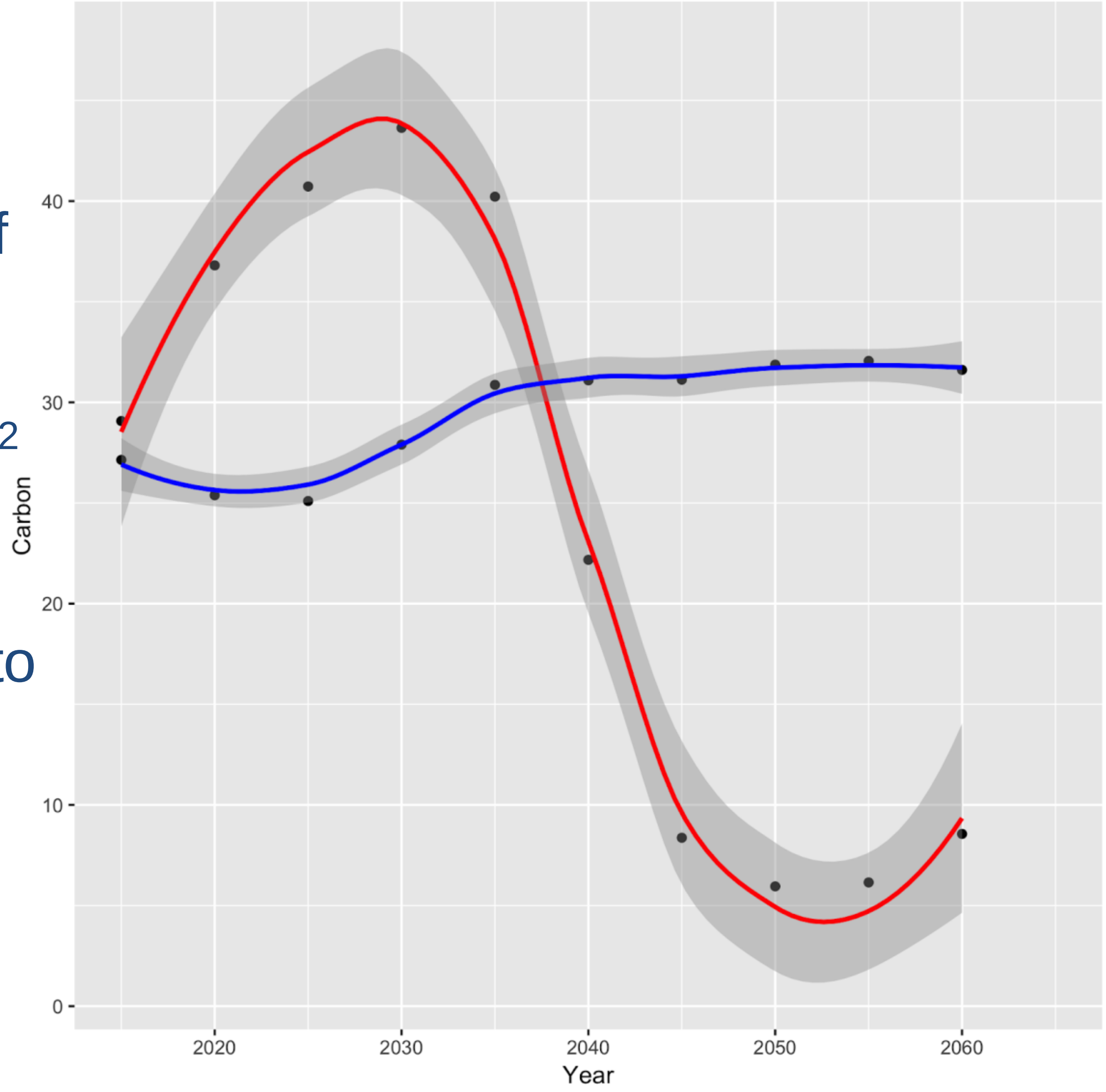
Cragin Carbon Methodology

Developed Forest Restoration Carbon Methodology - Determines carbon benefits of forest restoration projects

Cragin Case Study: Creates 25.9 tons of CO_2 benefits/restored acre over the life of the project

Next Steps: Model additional methodologies to compare results and apply to a restoration project



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Summary

Long Term Analysis - some results Spring 2021

- Continuous ongoing data gathering
- Monitoring trends

Uncertainties

- Evaporation rates?
- Evapotranspiration rates?
- Infiltration---increase, less, neutral?

Vegetation Adaptive Management

- What happens after thinning?

Long Term Water Augmentation Committee

Phreatophyte Management for Water Supply

Approach

Literature Review

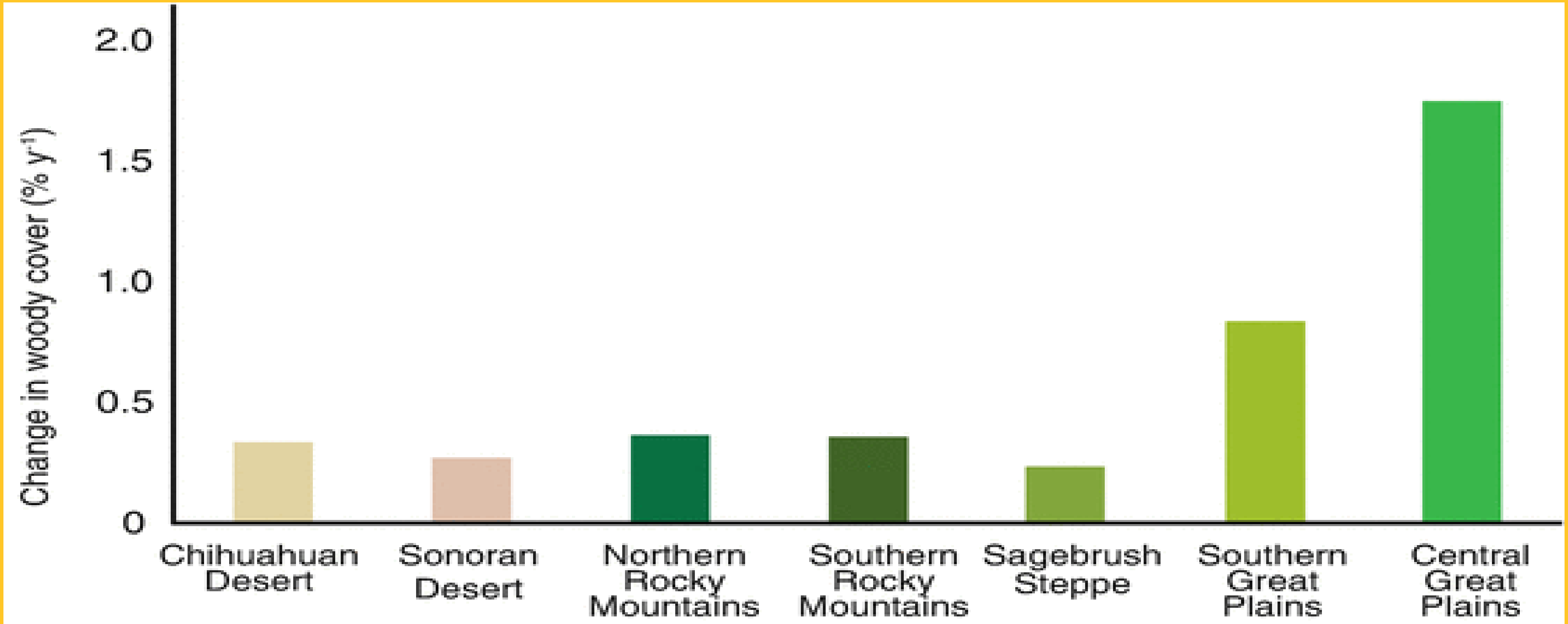
Interviews of Experts

What is a phreatophyte?

Deep-rooted plant

Draws water from vadose zone or water table

Encroachment Rates



Rates of woody plant encroachment in North American rangelands (Archer et al. 2017)

Can phreatophyte management increase water supply?

Complex & highly localized – not generalizable

Critical variables

- **ET rates of replacement vegetation**
- **Soil erosion & sedimentation**
- **Ongoing maintenance**

Long-term increases in water yield are likely only when a relatively high leaf area species is permanently replaced with a lower leaf area species.

Potential for improvements in soil health & watershed function

Conclusions

- Management of encroaching woody plants may yield watershed benefits
- Ongoing control / maintenance is costly
- Multidisciplinary, long-term site-specific studies are warranted

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